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Report of the Planning Group on North Sea Cod and Plaice Egg Surveys in the North Sea (PGEGGS)

22–24 November 2005

Charlottenlund, Denmark

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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H.C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Contents

Executive summary

The Planning Group on North Sea Cod and Plaice Egg Surveys in the North Sea (PGEGGS) was set up to address the fact that there had never been a complete ichthyoplankton survey of the North Sea. In particular, the need to monitor commercial fish spawning areas was identified by the Expert Panel which followed the Bergen Ministerial Meeting. Although spawning grounds can be monitored to some extent by adult trawl surveys, ichthyoplankton surveys have a number of potential advantages. Since individual fish spawn thousands of eggs it is often more reliable to sample the eggs rather than the adult fish and surveying spawning grounds of species producing planktonic eggs is also not restricted by bottom-type so a more complete spatial coverage can be achieved. In addition, if the area can be repeatedly surveyed over the spawning period, an estimate of total annual egg production can be made. When combined with fecundity data, such estimates are useful as additional stock assessments and can act as a validation of stock assessments made using standard methods based on commercial fisheries data.

Because of the current poor state of the cod and plaice stocks, it was decided to focus on those species. Early on PGEGGS undertook a literature review of all the available historical data in order to inform the design of the North Sea survey.

Given the scale of the proposed ichthyoplankton survey it was hardly surprising that it took several years to organise but finally in 2004 the field-work was undertaken. Over 500 plankton samples were analysed during 2004 and early 2005 including the application of a newly developed genetic probe for un-ambiguously identifying the early stage eggs of cod from those of haddock and whiting. The data were collated and analysed by PGEGGS and initial results presented at the ICES Annual Science Conference in the autumn of 2005. The purpose of the Copenhagen workshop in November 2005 was to undertake more detailed statistical analyses on the data. This has now resulted not only in the most complete maps of cod and haddock spawning areas in the North Sea ever produced but also distribution maps of several other species of interest, in an egg-production estimate for plaice in the southern North Sea and new insights into the relationship between hydrography and fish egg and larval distributions.

Clearly a single survey, even of the scale undertaken is of limited value since we need to build up a picture of changes over time. This is especially relevant as we are most probably entering a period of rapid environmental change that may exacerbate the conservation challenges of dealing with low stock sizes for valuable species such as cod and plaice. The Copenhagen workshop was therefore also asked to consider the case for repeating the 2004 exercise and what improvements should be made in any future North Sea wide ichthyoplankton surveys.

1 Opening of the meeting

PGEGGS met at Charlottenlund in Copenhagen from 22–24 November, 2005. Delegates were welcomed to Charlottenlund Castle by Peter Munk.

2 Adoption of the agenda

The TORs for the meeting were

a) undertake statistical analyses of data from the PLACES 2004 surveys;

b) to consider the feasibility of undertaking stock biomass assessments for North Sea commercial stocks using egg production methods;

c) produce recommendations on whether further North Sea egg surveys are required and guidance on their design in light of the experiences in 2004.

3 Participants

A complete list of participants is given at Annex I of this report.

4 Overall aims

At the PGEGGS meeting convened in Kiel (ICES CM 2004/G:03, Ref. D), six aims for the planned North Sea survey were set out:

a) Investigate all areas of the North Sea for the distribution of cod and plaice eggs;

b) Identify and delimit areas with high concentrations of cod and plaice eggs;

c) Trace the sites of intensive cod and plaice spawning based on distributional information of egg stages and larval sizes;

d) To attempt to estimate egg production for regions where there is sufficient survey coverage;

e) Correlate the distribution patterns of eggs and larvae to hydrographic features and investigate potential physical/biological linkages;

f) To describe where possible the distribution pattern of eggs/larvae of non-target (not plaice or cod) species.

During the spring of 2004 the field-work was completed. Analysis of the plankton samples and genetically identified eggs was completed by the following spring and a workshop held in Lowestoft (10–12 May, 2005: ICES CM 2005 G:11) to carry out initial analysis and to summarise the data. These initial results were reported at the ICES Annual Science Conference (CM 2005/AA:04). The purpose of the November meeting was to improve the statistical analysis of the data by modelling the proportions of cod, haddock and whiting and to consider the possibility of producing stock biomass assessments by egg surveys value of repeating the North Sea Egg Survey. In addition, delegates reported progress on the overall aims listed above and with producing published outputs from the survey.

5 Overall progress

Delegates reviewed bubble plots of all the eggs and larvae identified from the surveys. Although there was generally good, overall agreement across the surveys some problems were uncovered. It was noted that there appeared to be a discrepancy between the abundances of plaice eggs reported from the Dana surveys and those from adjacent sampling. Peter Munk has since had most of his samples re-analysed, checking for correct identification of plaice eggs as opposed to those of long-rough dab (*Hippoglossoides platessoides*). The corrected data have now been entered into the main database. A few eggs had been identified as bass (*Dicentrarchus labrax*) but were in an unusual location. These were also checked and corrected.

Sandeel (*Ammodytes*) larvae were not analysed from Netherlands cruises due to lack of time. Samples were transferred to Denmark and sandeel larvae sorted and counted. The data have been incorporated into the central database.

Following work after the November workshop, the database is now considered to be as complete as possible given logistical constraints. Copies of the final version of the database have been shipped to all PGEGGS delegates.

6 Progress with investigating all areas of the North Sea for the distribution of cod and plaice eggs (Aim a)

The surveys undertaken during the spring of 2004 successfully investigated the whole North Sea for cod and plaice spawning. The meeting agreed that aim a) had been completed.

7 Progress with identifying and delimiting areas with high concentrations of cod and plaice eggs (Aim b)

The bubble plots produced for the initial analysis of the data (CM 2005/AA:04) can be used to identify the areas of high concentration of cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*) eggs (Aim b). Since plaice eggs are relatively easy to identify, delegates were happy with the plaice data.

During this analysis it became clear that slight differences would arise depending on how the geneprobe data were used to assign proportions of unidentified ‘cod-like’ eggs. This issue arises since on any station where only subsets of the cod-like eggs were genetically identified. On stations with low numbers of ‘cod-like’ eggs this may lead to too few positively identified results to accurately ascribe a proportion. On a few stations, ‘cod-like’ eggs were found when the formalin fraction of the sample was analysed but no eggs had been pre-sorted for genetic probing. In addition, there was some variation between the levels of sub-sampling attained by different countries. The initial analysis of the data attempted to allocate ‘cod-like’ eggs on a station by station basis but this inevitably led to gaps in certain areas.

The next method attempted was to compute the percentage of cod:haddock:whiting:other eggs by strata. Strata were designed to be as small as possible but to contain results from at least 30 genetically identified eggs. The overall egg distribution patterns by species were consistent regardless of which allocation method was used. The workshop accepted that the maps based on strata were useful as a baseline to compare with formal modelling. If one assumes that the ratio of cod to other species should change relatively smoothly in space, then it should be possible to spatially model the ratio using smoothing techniques. This was investigated during the workshop.

The proportion of eggs at each station for the four species cod, haddock, whiting and others was modelled using a multinomial distribution. Proportion was related to position with a smoothed spatial surface based on natural splines with 24 df for Latitude, Longitude and Latitude*Longitude.

eggs.mul.ns24 <- multinom (eggs.in ~ ns(Lat, df=24) + ns(Long, df=24) + ns(LatLong, df=24), data=eggcounts.dat)

The choice of 24 df was partially subjective because increasing the df always gave a statistically significant improvement in fit (up to 60df which was the maximum tried). Above 24 dfs the improvement in fit for subsequent increases of 4 df per spline was less than the improvement from 20 to 24df. Using 24df gave a better fit than using Strata and required 6 fewer df. The shape of the fitted splines with 24df showed a combination of smooth changes and local variation at a scale of approximately half a degree. Plots of model residuals against position and time showed no major problems.

The fitted model was used to predict proportions by species at all stations, including those not sub-sampled for species identification. The predicted proportions at each station were then multiplied by estimated egg abundance to give estimated egg abundance by species.

Modelling was carried out in R v2.2.0 with additional functions from libraries splines and net.

The second question considered by the workshop was whether one should model each egg developmental stage separately, or to combine all the stages. Ideally using data from stage I only would best identify spawning grounds since the eggs will be only a few days old or less. On the other hand, using all the developmental stages yields considerably more data and might improve the model fit. The main reason why one should not adopt the latter approach is if eggs could have been advected a significant distance during their development. The workshop discusses this issue. At the sea temperatures encountered during the survey, cod eggs will take between 14–21 days to develop. Although the working group did not have formal hydrographic models available, consideration of the maximum residual currents in the southern North Sea (3 km per day) suggested that eggs would not travel more than about 60 km up to hatching (Simpson, 1959). Since the inter-station spacing was of the order of 20–30 km, a maximum drift over two stations would have a minor impact in distorting mapped egg distributions. The group concluded that given the additional data made available, modelling should proceed on the basis of using all developmental stages but that the issue of egg drift should be re-examined once a suitable particle tracking IBM was available. Clive Fox reported that such a model was in development at CEFAS and should be useable sometime in 2006 whilst Mark Collas reported that he had access to such a model for the southern North Sea.

Based on the multinomial modelling approach maps of the distribution of cod, haddock, whiting and other species were produced (Figures 7.1–7.4).

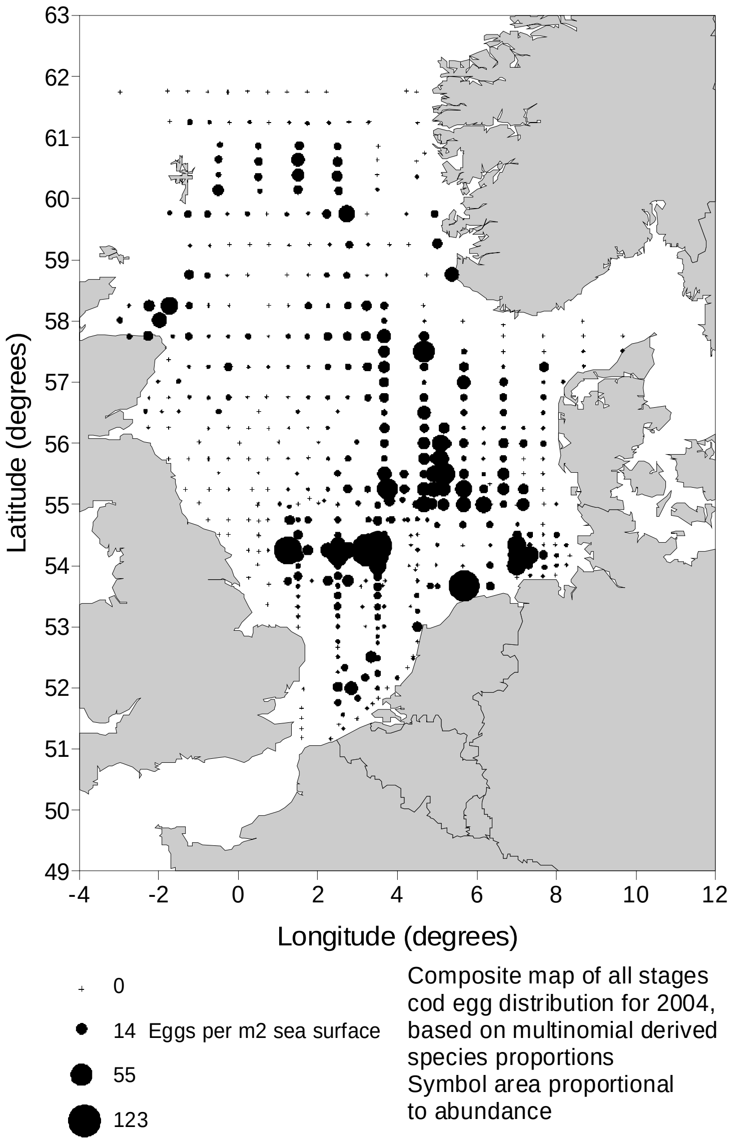


Figure 7-1: COD egg distribution (all developmental stages) in 2004.

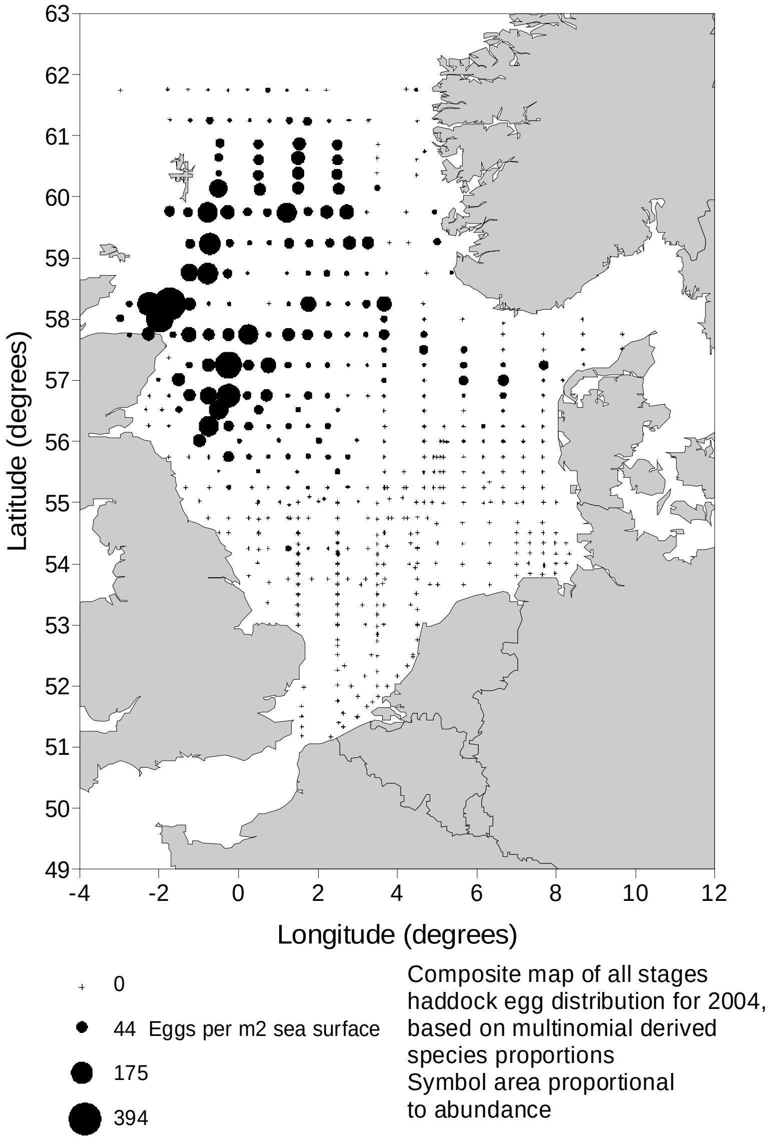


Figure 7-2: HADDOCK egg distribution (all developmental stages) in 2004.

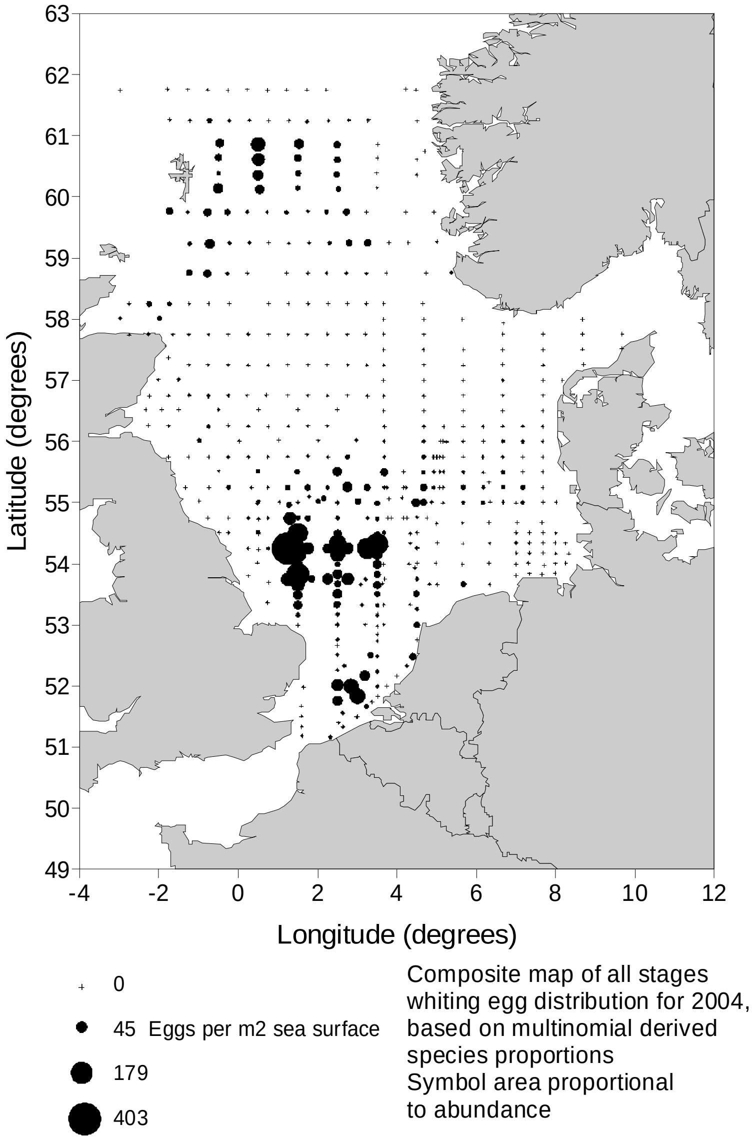


Figure 7-3: WHITING egg distribution (all developmental stages) in 2004.

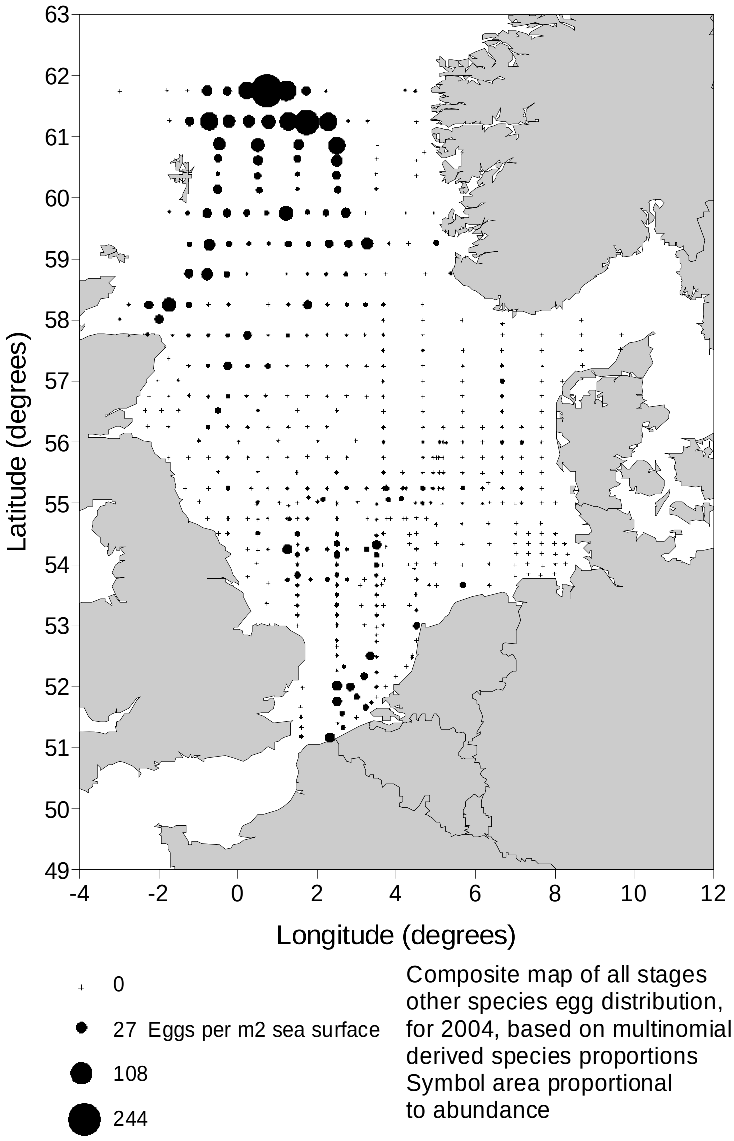


Figure 7-4: OTHER SPECIES WITH COD-LIKE EGGS (eggs of diameter 1.1 – 1.75 mm and lacking oil globules or other distinguishing features) - distribution (all developmental stages) in 2004.

The third issue examined was the effect of converting from egg abundance (numbers m^{-2} sea surface) to daily production (nos m^{-2} sea surface day^{-1}). Since sea temperatures differ across the North Sea and egg development rates are related to temperature, not accounting for this might lead to some bias in mapped distributions. This correction was applied during the workshop to the cod data using a published temperature development model (Thompson, 1981). We were unable to find such a model for the development of North Sea haddock eggs so used a relationship from (Page, 1989). Comparing the maps for cod egg abundance and production and for haddock egg abundance and production showed that correcting for temperature only had a minor effect on spatial distribution (Figures 7.5–7.6). Note that accounting for temperature does affect the maximum values since these are inversely scaled by the duration of egg incubation.

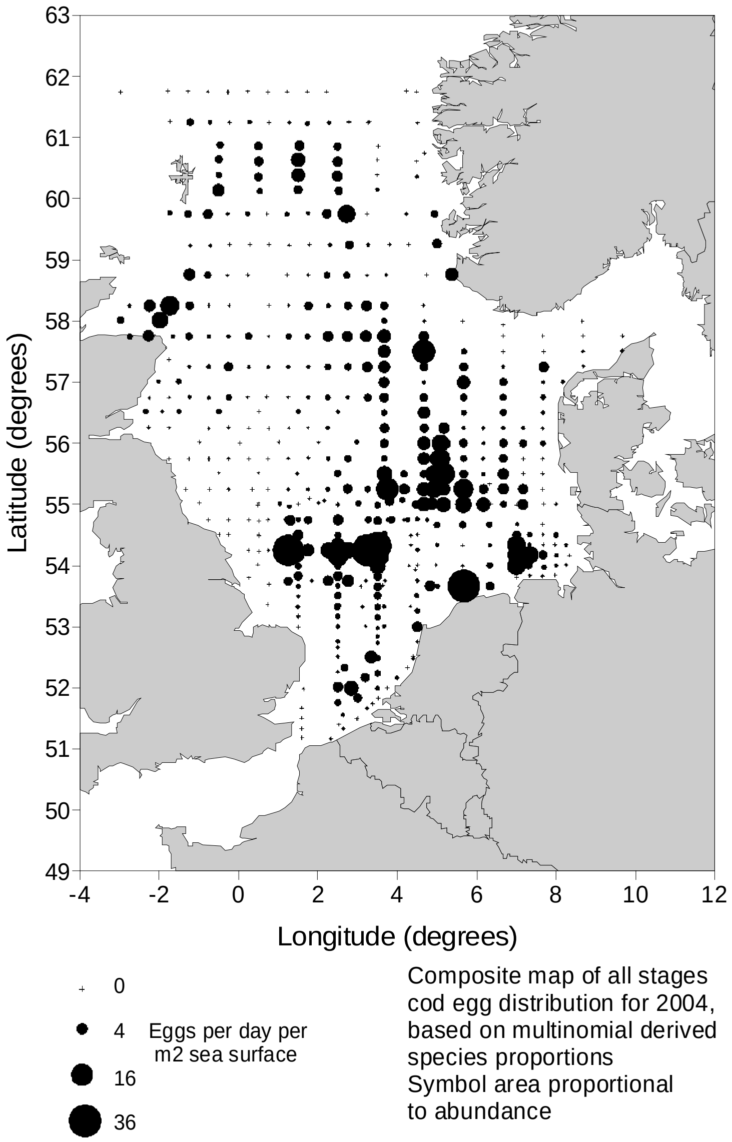


Figure 7-5: COD egg distribution (all developmental stages) in 2004 corrected for the effect of different temperatures on the development rates.

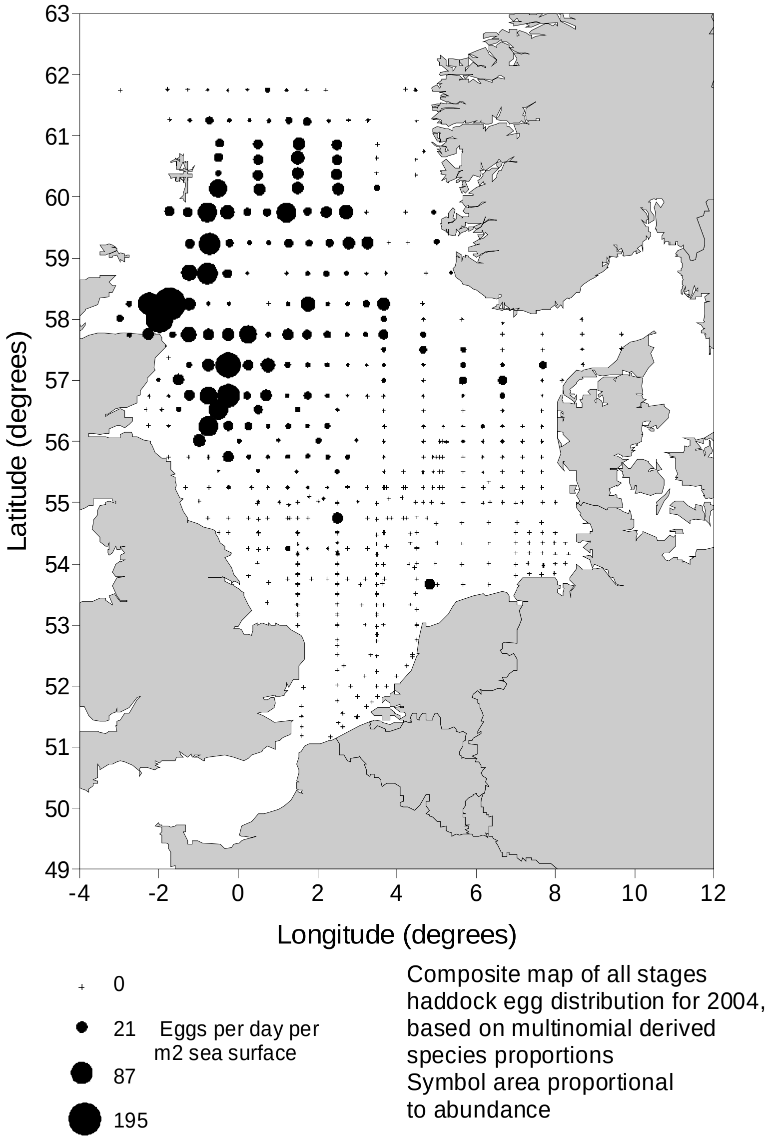


Figure 7-6: HADDOCK egg distribution (all developmental stages) in 2004 corrected for the effect of different temperatures on the development rates.

8 Trace the sites of intensive cod and plaice spawning based on distributional information of egg stages and larval sizes (Aim c)

An analysis of the distribution of cod eggs by developmental stage and latitude does not show any obvious patterns of re-distribution of the eggs over time. This suggests that the eggs from localised spawning areas disperse over time and are not subjected to strong north-south advection. Evidence from comparing the cod egg and larval distributions suggests more significant drift of cod early life stages in a west to east direction in the southern and central North Sea.

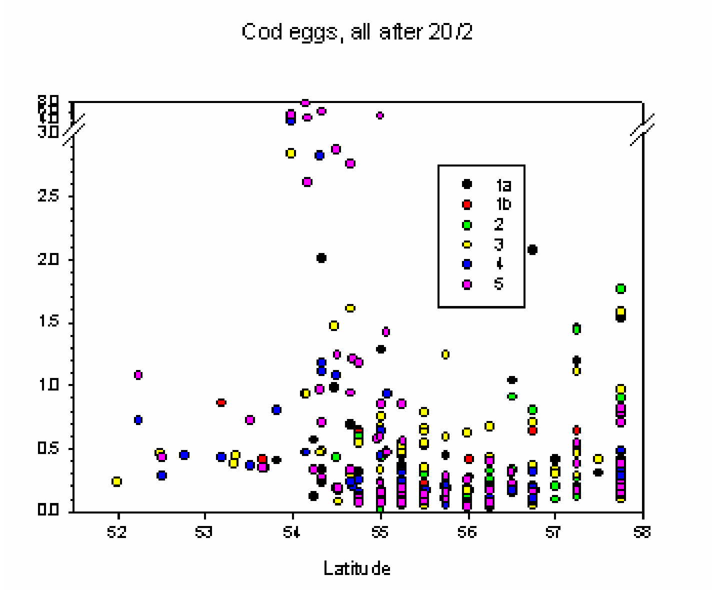
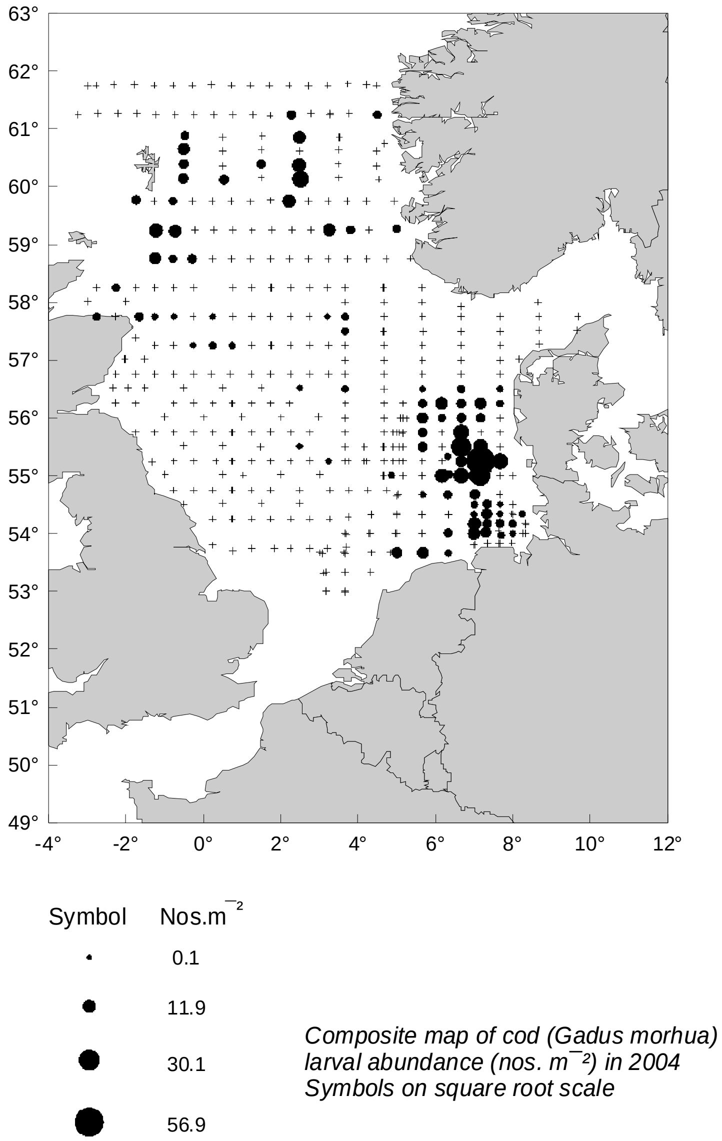


Figure 8-1: Relationship between cod egg abundance, developmental stage and latitude.

There was insufficient time at the meeting to examine larval distributions by size. However, maps of cod and plaice larvae have been produced (Figures 8-2 and 8-3). The larvae shown would have come from spawning up to three weeks previously. Care should therefore be taken in drawing inferences about transport routes from the raw data.

The general distribution of cod larvae conformed to literature references that suggest that concentrations of cod larvae in the North Sea were found in the German Bight (Daan, 1978). Additional patches of cod larvae at lower concentrations were found east of the Shetland Isles and off the Moray Firth. The distribution of larvae was in good accord with the maps of cod eggs produced. Further work using particle-tracking models will be required to fully map the dispersal pathways for cod eggs and larvae in 2004.

Plaice larvae were reported from the German Bight and inshore areas of the southern North Sea. Smaller concentrations of larvae were found close to the Scottish coasts. Again, the general distribution of larvae was in line with patterns expected based on the occurrence of the eggs.



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57°
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53°
52°
51°
50°
49°
-4°
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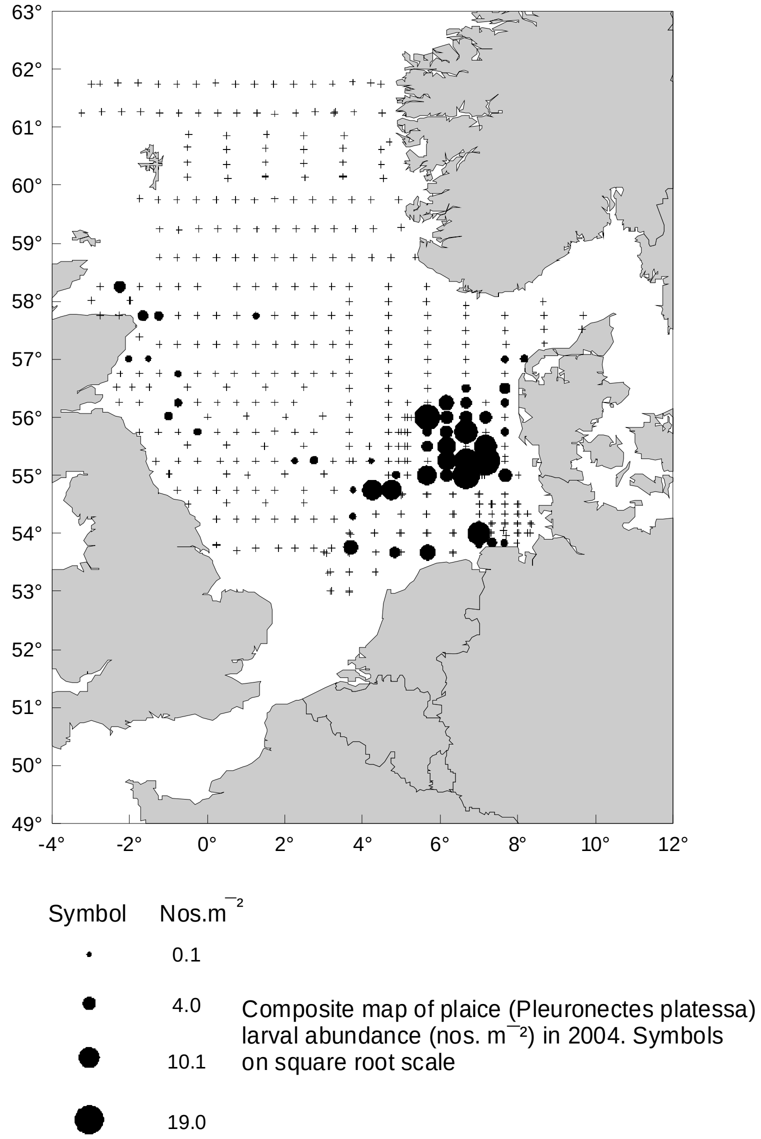
0°
2°
4°
6°
8°
10°
12°
Symbol
Nos.m⁻²
0.1
11.9
30.1
56.9
Composite map of cod (Gadus morhua)
larval abundance (nos. m⁻²) in 2004
Symbols on square root scale

Figure 8-2: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4°
6°
8°
10°
12°
Symbol
Nos.m⁻²
0.1
4.0
10.1
19.0
Composite map of plaice (Pleuronectes platessa) larval abundance (nos. m⁻²) in 2004. Symbols on square root scale

Figure 8-3:

9 To attempt to estimate egg production for regions where there is sufficient survey coverage

The group considered that it should be possible to produce an estimate of overall egg production for areas covered by a minimum of five surveys during the spawning season. Realistically this restricts the suitable region to the southern North Sea and to plaice. For the main spawning grounds of cod, being more northerly distributed, the survey design did not allow for a full temporal coverage. However, areas B, C and D have been covered by at least 3 surveys, PGEGGS will in addition attempt to estimate the area specific annual egg production of cod in this region.

9.1 Cod egg production

Based on recorded water temperatures, station specific cod egg abundances have been converted into daily production values (Figure 9-1). The daily egg production was calculated as the abundance of stage I eggs divided by the stage duration estimated from stage-specific egg development-temperature relationships (Thompson and Riley 1981). The temperatures used in the relationships were derived from corresponding station specific CTD casts and temperatures were calculated as averages over the water column. Due to a lack of available information on egg mortality of North Sea cod, no correction for early egg mortality has been applied.

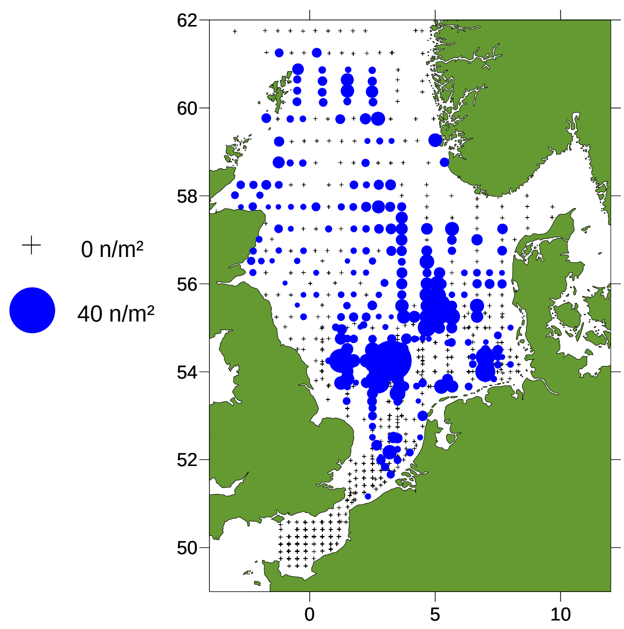

Figure 9-1: Daily production of stage I cod eggs. Symbol area on log scale.

In order to obtain area specific production values, squares of four ICES rectangles will be established and averages of all stations laying within a square will be calculated. According to Daan (1981), daily cod egg production of the youngest egg stage is normally distributed over time. A transformation to natural logarithms converts these normal distributions into parabolas. Based on this assumption, we will try to fit second order polynomials to the transformed area specific daily egg production estimates for each cruise applying the least-squares method. If data quality allows fitting seasonal production curves, the annual egg production, i.e. the area beneath the fitted curves, will be estimated by numerical integration of re-transformed data. In order to obtain stock estimates of cod maturity data from the third quarter IBTS as well as 2003 / 2004 fecundity data from the southern North Sea (Peter

Witthames, pers. comm.), and the Northern North Sea for 2003 (Yoneda and Wright, 2004) will be applied. Precision of the stock estimate will be limited by the number of egg samples per date and area as well as the lack of sex ratios and sex specific maturity data from the IBTS. This work will be completed during 2006.

9.2 Annual Egg Production estimates of North Sea plaice

The Annual Egg Production (AEP) method has been used successfully to estimate spawning stock biomass in determinant spawning fish (Parker, 1980; Lasker, 1985; Armstrong *et al*., 1988; see Hunter and Lo, 1993). It has proved useful to both investigate the trends in SSB in certain stocks (Simpson, 1959; Lockwood *et al*., 1981; Priede and Walsh, 1991), one off SSB estimates (Bulman *et al*., 1989; Zeldis, 1993), to compare biomass estimates derived from catch-at-age based stock assessments with fishery independent assessments (Daan, 1981; Heessen and Rijnsdorp, 1989; Horwood, 1993a; b; Armstrong *et al*., 2001 Zenitani, *et al*., 2001) or the spatial distribution of spawning components (Fox *et al*., 2000; Heffernan *et al*., 2004). A similar technique (the larvae production estimate LPE), has also been used to investigate the trends in stocks with attached or benthic eggs (Nichols *et al*., 1987; Heath, 1993; Fossum, 1996; Briggs *et al*., 2002). It can be argued that the SSB estimates from AEP are more useful for fish ecology or management than those derived from aged based VPAs (the sum for all ages of number * weight * the proportion mature), as they measure reproductive production directly, and are not inferred from XSA derived matrices of numbers and weights at age.

The wide coverage with high resolution (both spatial and temporal) of the PLACES ichthyoplankton surveys of the North Sea meant that another AEP estimate of North Sea plaice SSB could be carried out. With this in mind, the fecundity of North Sea plaice was also investigated in 2004. Data from previous ichthyoplankton surveys of the southern North Sea were also available (Simpson, 1959; Heessen and Rijnsdorp, 1989; Land, 1991) and thus the relative trends in the North Sea plaice stock and variability in the spatial pattern of spawning could be investigated. This is important for two reasons:

i) The catch-at-aged based stock assessment of North Sea plaice has changed greatly in recent years. Large retrospective changes in the estimated absolute levels of plaice SSB in the North Sea have occurred (Figure 9-2; and Pastoors, 2005), and now the stock assessment incorporates discarding of plaice. The incorporation of discarded plaice is done by the use of raised discard estimates from sampling the fleet in recent years and the use of an inter-annually varying growth model that simulates potential discarding behaviour of the fleets back in time (Keeken *et al*., 2003; ICES, 2006). This new method has never been sensitivity tested (STECF 2005) and further information is required to support the use of this new technique.

ii) The spatial distribution of juvenile plaice has reportedly changed in recent years (Keeken *et al.*, 2004), and there is anecdotal evidence coming from the fishery that the relative distribution of the adults may also have changed. Plaice in the southern North Sea is partially managed through spatial closures, designed to protect juvenile plaice (Rijnsdorp and Beek, 1991; Pastoors *et al*., 2000). There are also predictable spatial patterns in fishing mortality per effort of the fleet (Rijnsdorp *et al*., 2005). Thus within this spatial context of both fish and fleet behaviour, any evidence for changes in relative distribution of spawning plaice should also be investigated and the findings considered.

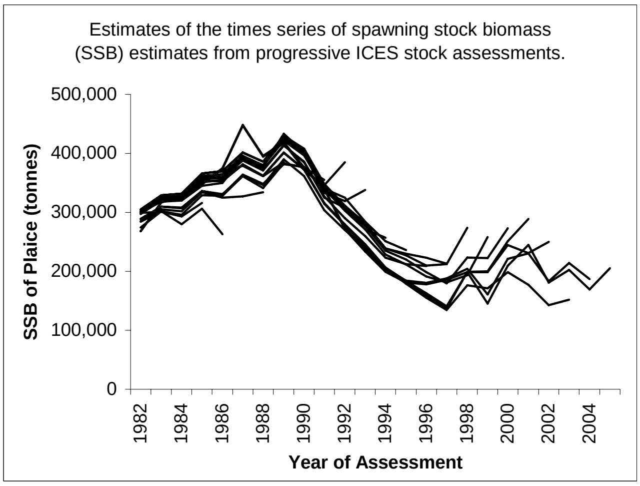

Figure 9-2: North Sea plaice – Historic retrospective pattern in the estimation of SSB of North Sea plaice by successive ICES stock assessment working groups (source ICES data quality sheets).

9.2.1 Methods

9.2.1.1 Ichthyoplankton surveys

The methods used, and coverage (both spatial and temporal) are already described in detail in ICES (2005). No additional ichthyoplankton surveys were carried out specifically for the AEP estimation. As no temperature data were collected during the first cruise in area A, 9°C was assumed to be the temperature for all samples from that cruise.

9.2.1.2 Estimation of fecundity of North Sea plaice

In December 2003 and January 2004 freshly caught female plaice were collected from a Dutch beam trawler the “Arnemuiden 44” and RV “Tridens”. Plaice were collected from three different areas in the southern North Sea (Figure 9-3). The numbers of fish sampled are summarised in Table 9.1.

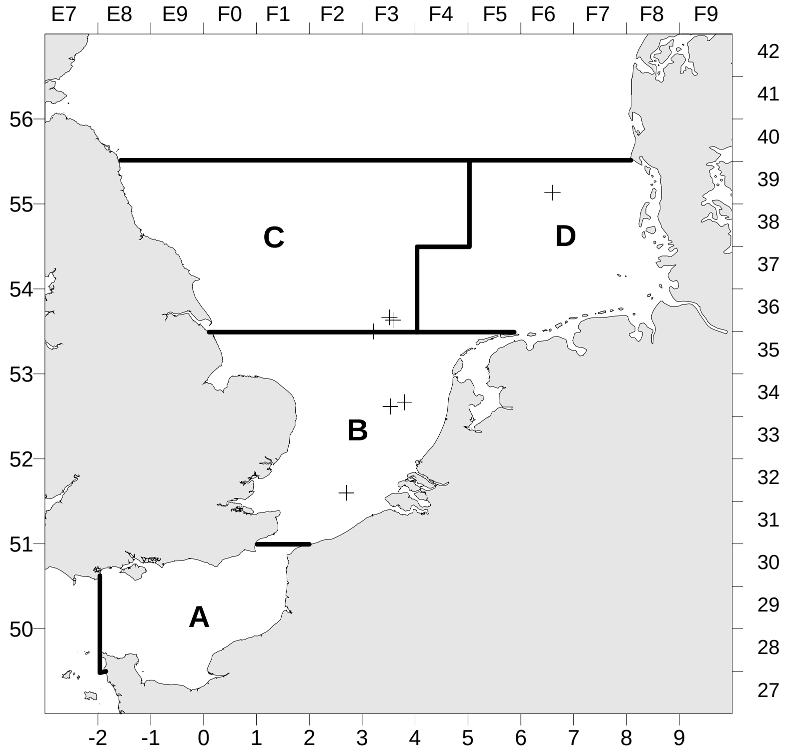

Figure 9-3: Location of plaice sampling for fecundity estimation in December 2003 and January 2004 and area division for the 2004 egg survey. A-eastern Channel, B- Southern Bight, C- Dogger Bank, D-German Bight.

Table 9-1: Sampling of Plaice for estimation of fecundity December 2003/January 2004. Of each female duplicate pipette samples were taken for fecundity estimation. See also Figure 9-3 for locations.

Sample Number	Sample Area	Sample Date	Number of females
1	Southern Bight (B)	3-12-2003	17
2	Dogger Bank (C)	2-12-2003	19
3	German Bight (D)	11-12-2003	21
4	Dogger Bank (C)	11-12-2003	34
5	Southern Bight (B)	18-12-2003	23
6	Southern Bight (B)	07-01-2004	19
7	Dogger Bank (C)	06-01-2004	26

The following biological parameters were collected of each fish: total length, weight, maturity and ovary weight. Of each fish duplicate (one of each ovary) ocyte samples were taken with a solid displacement pipette, with a known volume of 100 µl (Damme *et al.*, 2005). The ovary samples were preserved separately in 2 ml of 3.6% buffered formaldehyde.

The opaque oocytes were coloured using PAS staining (Periodic acid followed by Schiff's reagent) and fecundity was estimated with an auto image analysis system (Thorsen and Kjesbu 2001; Damme *et al*., 2005). Threshold for vitellogenic oocytes was set at 450 µm. Whenever hyaline or post-ovulatory follicles (POFS) were present in the samples, these fish were rejected for the fecundity estimation, since they had already started spawning.

Fecundity was calculated using the formula:

$$F = N/s * W \qquad (1)$$

where F is fecundity, N is the number of vitellogenic oocytes in the pipette subsample, s is the subsample weight and W the total weight of fish.

9.2.1.3 Temperature based egg development rates

Temperature development rates were calculated using the equations from Ryland and Nichols (1975):

$$D = (100/(aT+b)) + D0 \quad (2)$$

and Fox *et al*. (2003):

$$D = a + b * \ln(T) \quad (3)$$

where D = Development time till the end of the development stage, T is temperature (°C) and D0, a and b are constants (Table 9-2).

Table 9-2: Constants used for the calculation of development time till the end of each stage, using models 2 and 3.

Stage	Ryland and Nichols (1975)			Fox *et al.* (2003)	
	a	b	D0	a	b
1A	0.6203	8.9372	-5.5639	5.186	-1.612
1B	2.3629	4.6528	-1.2662	8.002	-2.540
2	2.1274	0.9166	-0.2867	12.819	-4.098
3	1.0642	1.5260	-1.7543	25.398	-8.078
4	0.7299	1.3619	-2.7171	29.880	-9.313
5	0.3150	1.3153	-10.4479	43.853	-14.427

9.2.1.4 Assumed Egg Mortality

As egg production estimates are made at the median age of an egg stage (often for just stage 1A or 1), a mortality rate of eggs must be assumed or calculated to estimate the numbers of eggs at the immediate time of spawning (i.e. time=0). In this analysis we assumed egg mortality rates based on previous studies (e.g. Harding *et al*., 1978; Heessen and Rijnsdorp, 1989; Land, 1991; Dickey-Collas *et al*., 2003) and did not use the decline in daily production of eggs by stage to estimate M specifically. AEP estimates were made using the following constant mortality rates (Z): 0, 0.10, 0.15, 0.20, 0.25 and 0.29. In addition mortality of eggs was estimated based on temperature using the equation from Dickey-Collas *et al*. (2003)

$$\ln(Z) = 0.40 * T – 4.79 \quad (4)$$

where Z is mortality rate and T temperature (°C) for each haul.

9.2.1.5 Estimation of annual egg production

The methods were developed from those described in Heessen and Rijnsdorp (1989) and Armstrong *et al*. (2001). The estimation of AEP was carried out using SAS. Abundance of eggs and egg production was calculated for each development stage (1A, 1B, 2, 3, 4, 5). The abundance (nos per m^2) of plaice eggs by stage were converted to the daily production of plaice eggs by stage (nos per m^2 per day) using the integrated water column temperate (^oC) for each sample and the egg development to temperature relationships described in equations 2 and 3.

For the estimation of annual egg production only the daily productions of stage 1A eggs were used. The daily production at each station was back-calculated to the production at time of spawning by using an assumed mortality rate (Z) and the median age of those eggs (based on the temperature at that station).

$$P_{t0} = P_{t1A} * \exp^{(-zt)} \quad (5)$$

where P is egg production, t is the time between t_0 (time of spawning) and t_{s1A} (median time of egg stage 1A) and Z is the coefficient of daily mortality. Different values of Z were used to test the sensitivity of estimates of daily production to assumptions about Z. Estimates of daily production at time of spawning were made for Z=0 up to Z=0.29. It was considered that since sampling was continuous throughout each day and night, the mean development duration of stage 1A eggs indicated the half way point (median) of the 1A stage duration (t in equation 5 above). This assumption is incorrect due to the exponential decline in fish eggs after spawning and will result in an slight over estimate of egg production, depending on Z (see Dickey-Collas *et al*., 2003). However the median stage duration was used for simplicity.

To raise production estimates by area to absolute numbers, total egg production was estimated by first calculating the mean daily production per ICES rectangle. For each survey area (Figure 9-3), the egg production per cruise was then calculated by taking the weighted mean production of all ICES rectangles productions.

The annual daily production curves were estimated by determining the mid point of the survey for each area and cruise and then determining the total annual production from these mid points and the daily production associated with each cruise (see Armstrong *et al*., 2001).

9.2.1.6 Estimating Spawning stock biomass

Fecundity was estimated for each of the three areas as well as for the whole of the Southern North Sea (see above). SSB was then calculated for the different areas using the area fecundity estimates and the estimated annual egg production. Summing all the areas gave a total SSB. A second method was used which did not consider the fecundity estimates as from any specific area, and in this case the SSB was estimated by summing the area annual productions and dividing by the mean fecundity for the whole region. No atresia was assumed. Sex ratio was considered to be 1:1.

9.2.1.7 Reworking of the old time series

The raw data of the 1987 and 1988 egg surveys carried out by Heessen and Rijnsdorp (1989) was used to re-estimate annual egg production and SSB using the above described method. However fecundity estimates from Rijnsdorp (1991) were used rather than the estimates from 2004. In order to be able to compare data between both periods the 2004 estimates were also calculated using the area division from Heessen and Rijnsdorp (1989) (Figure 9-4).

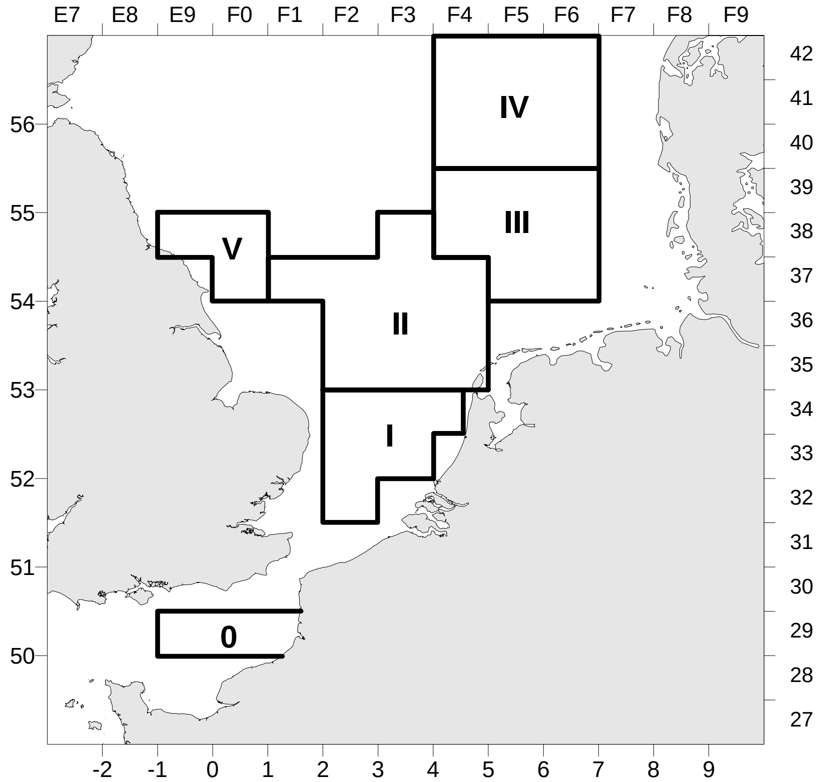

Figure 9-4: Survey area and divisions used by Heessen and Rijnsdorp (1989).

9.2.1.8 Data from stock assessments

The current estimates (XSA derived) were taken from the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, 2006). The ICES stock assessment assumes a constant maturity ogive.

9.2.2 Results and Discussion

9.2.2.1 Spatial and Temporal coverage of surveys

Areas B and C (see Figure 9-) had sufficient surveys to carry out full AEP estimates for plaice (Table 9-3). The surveys in these areas had good temporal coverage so that the onset and decline in spawning was covered. Less surveys occurred in areas A and D. The end of spawning was missed in area A (last estimate 21 January 2004) and the beginning was missed in area D (first estimate 15 January 2004). If spawning is assumed to be similar to previous years, as described in earlier studies, then dates for zero productions can be assumed to allow AEP estimates to be derived.

Table 9-3: Number of daily egg production estimates available per survey area (see Figure 9-2) to create annual egg production curves.

Survey Area	A	B	C	D
No of mean daily egg production estimates	3	7	6	5

9.2.3 Estimation of fecundity of North Sea plaice

A significant difference in the total fecundity at length between the areas was found (Figure 9-5). Fecundity in the Southern Bight and Dogger Bank were the same, but fecundity in the German Bight was significantly lower ($P<0.000$). Compared to the fecundity estimates from Rijnsdorp (1991) in the 1980s fecundity in all areas was higher (Table 9-4).

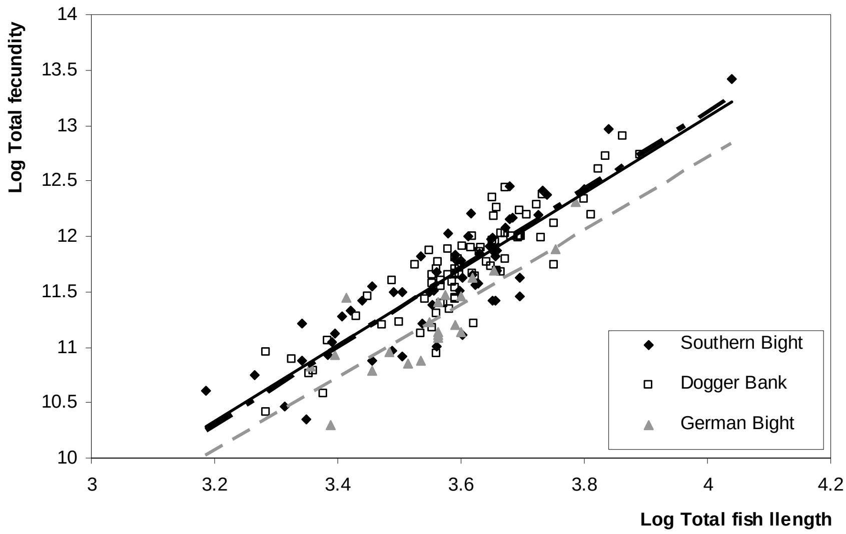

Figure 9-5: Plaice total fecundity for the three different areas sampled, see Figure 9-2 for areas.

Table 9-4: Plaice potential fecundity estimates (oocytes per g female) for the three different areas samples and total Southern North Sea, for comparison with Rijnsdorp *et al.* (1991).

Area	Potential fecundity (eggs per gramme female)	Standard deviation
Southern Bight (B)	255	63
Dogger Bank (C)	235	51
German Bight (D)	185	43
Total Southern North Sea	238	58
Total Southern North Sea 1982-1985 (Rijnsdorp 1991)	171	

9.2.3.1 Effect of development rate

Since the study of Heessen and Rijnsdorp (1989), new studies on temperature dependent egg development rates have been carried out. These were described and summarised in Fox *et al.* (2003). However these more recent studies were on Irish Sea plaice but did use many more fish and more mixed parenting to weaken maternal or paternal effects. It is clear that whilst the new relationships from Fox *et al.* (2003) do have an effect on the estimation of production, it is small. For example in area B- the Southern Bight (Figure 9-6), using the Fox *et al.* relationships production of stage 1A at median age is estimated to be 89% of that using Ryland and Nichols (1975, Table 9-5). Due to the higher sea temperatures at the time of sampling in area A, this are shows the biggest difference dependant on assumed temperate to egg development relationship.

Table 9-5: Mean difference in the estimation of stage 1A egg daily production at median age using Fox *et al.* (2003) and Ryland and Nichols (1975) by survey area.

Survey area	mean difference (%) in estimate of daily egg production of Fox compared to Ryland and Nichols	mean sea temp in area °C
A	0.72	9.57
B	0.89	7.38
C	0.97	6.90
D	0.98	6.37

Estimates are not weighted by egg abundance and based on the unweighted mean of cruises in each area.

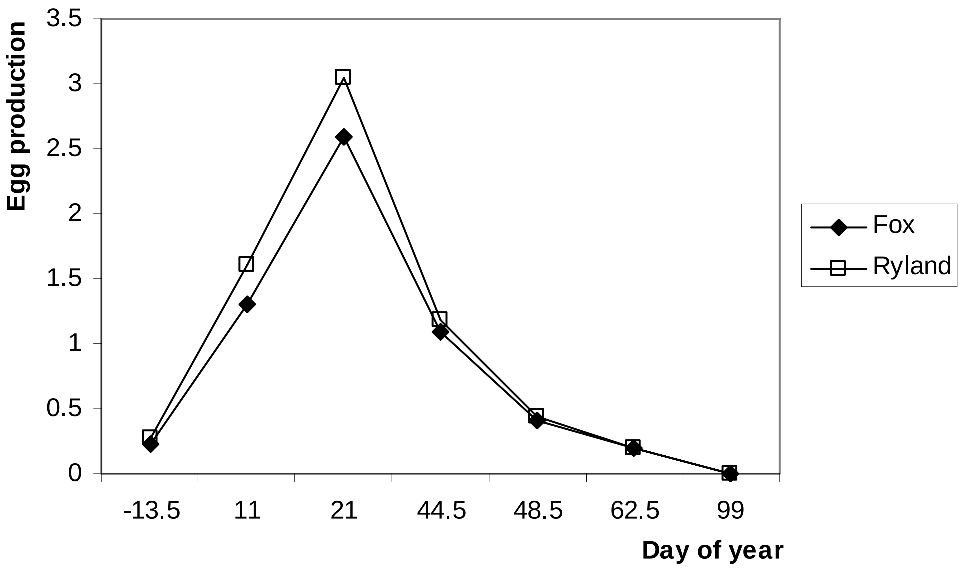

Figure 9-6: Comparison in Area B of the seasonal egg production of North Sea plaice in 2004 determined using egg development to temperature relationships from either Ryland *et al.* (1975) and Fox *et al.* (2003). Egg production is nos per m^2 per day, and is estimated at the median time of stage 1A developmental stage (i.e. Z=0).

9.2.3.2 Effect of assumptions about egg mortality (Z)

The current study did not try to estimate egg mortality rates. However to investigate the difference in the estimates of daily production at median egg age and at spawning (i.e. time = 0) a range of mortality rates were assumed and applied to the median age production estimates. As to be expected the higher mortality rates resulted in higher estimates of egg production at spawning (Figure 9-7). The mean difference (unweighted) from median age daily production of stage 1A (Z=0) and spawning production with Z=0.2 was an increase of 16% in area A, 21% in area B and 24% in areas C and D.

However when Z was also assumed to be related to sea temperature following Dickey-Collas *et al*. (2003), the area effect on the differences was more dramatic (Table 9-6). The higher temperatures in area A resulted in a 37% increase in production of median aged stage 1A eggs and production at spawning time. This impact was less in the other areas (Figure 9-8).

Table 9-6: Assumed daily egg mortality rate (based on Dickey-Collas *et al.*, 2003) and its impact on the estimate of egg production at spawning from back calculations of production at median age stage 1A.

Area	Mean sea temperature °C	Mean assumed daily Z	Mean difference between median age stage 1A production and production at spawning
A	9.57	2.17	37%
B	7.38	1.19	21%
C	6.90	0.66	14%
D	6.37	0.93	13%

Estimates are not weighted by egg abundance and based on the unweighted mean of cruises in each area.

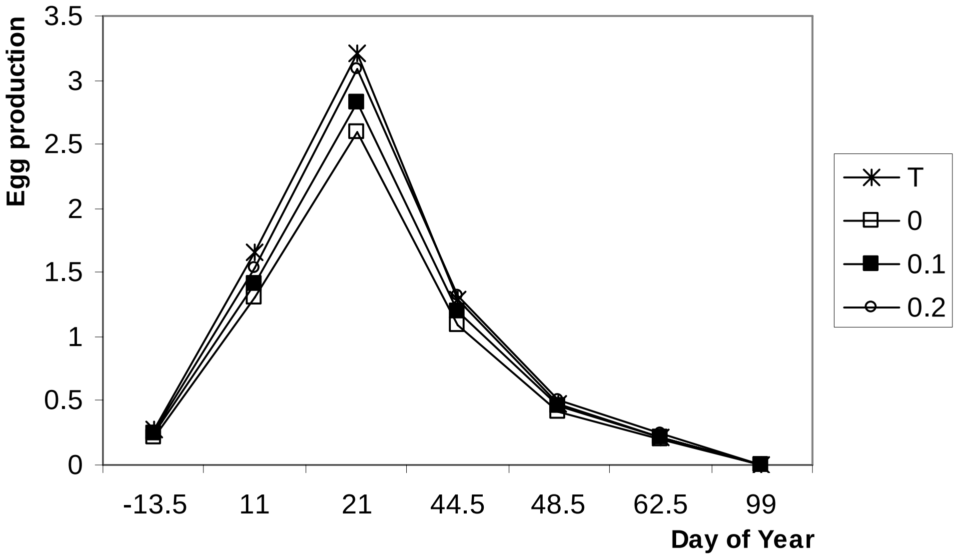

Figure 9-7: Comparison in Area B of the influence about assumptions in egg mortality in the seasonal egg production of North Sea plaice in 2004. Egg production is nos per m² per day, egg development is based on Fox *et al.* (2003). Production is estimated with Z=0.0, 0.1, 0.2 and T- the temperature to egg mortality relationship in Dickey-Collas *et al.* (2003).

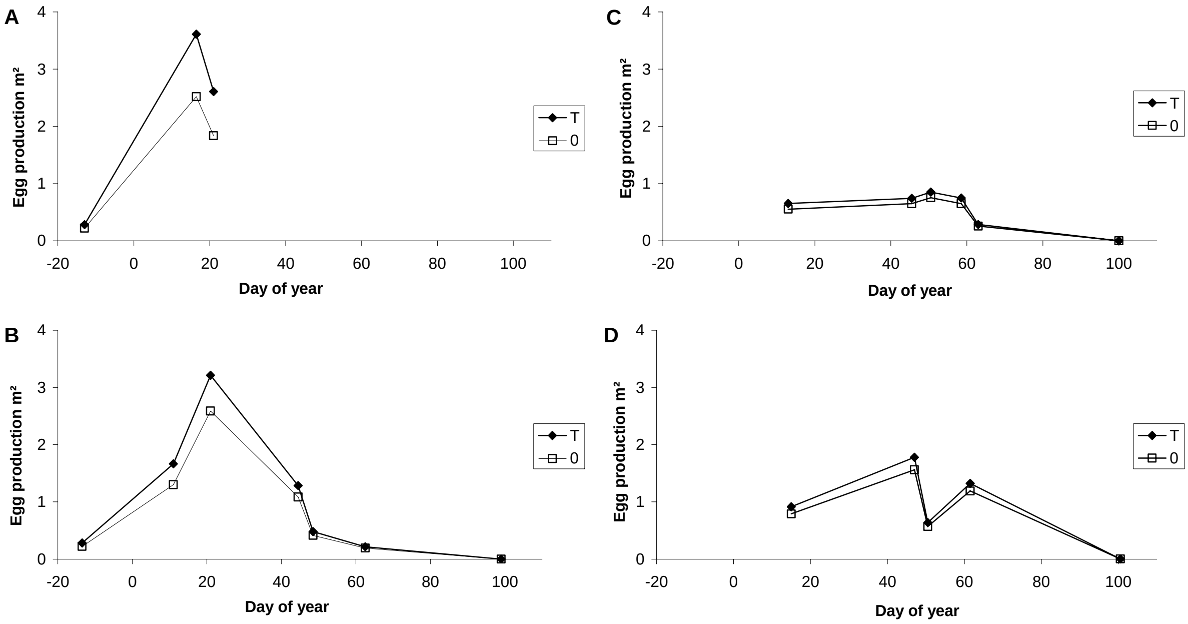

Figure 9-8: Comparison of the seasonality in daily egg production of North Sea plaice in 2004 in survey areas A, B, C and D (see Figure 9-3). Egg production is nos per m² per day, egg development is based on Fox *et al.* (2003). Daily production is estimated with Z= T- the temperature to egg mortality relationship in Dickey-Collas *et al.* (2003) and at time of capture (i.e. Z=0, median age stage 1A). Day of year =0 is 1st January 2004.

9.2.3.3 Daily egg production by area

The seasonal trend in egg production varied by area (Figure 9-8). The smaller area A (see Figure 9-3) had equivalent maximum egg production per m² to area B. Areas C and D had lower production per m². Another survey in area A about day 40 would have been very useful.

Likewise a survey in early January in areas C and D would also provide useful data. The peak in production appeared earlier in areas A and B compared to C and D (Figure 9-8) and A and B appeared to have a more marked peak compared to C and D.

9.2.3.4 Annual egg production and SSB estimates for 2004

The production curves in egg daily production were summed and raised by area to determine the annual egg production (Table 9-7). Areas B and D appeared the most important for the production of plaice in the southern North Sea. Combining these AEP estimates with fecundity estimates and an assumed sex ratio of 1:1, resulted in a minimum total biomass of North Sea plaice in 2004 of a of 145 Kt (based of production of median aged stage 1A eggs), and a likely maximum of 174 Kt (based on the production at spawning time, and assuming egg mortality to vary with local temperature following Dickey-Collas *et al*., 2003). The use of the more poorly estimated (but North Sea targeted) Ryland and Nichols (1975) egg development relationships resulted in a minimum estimate SSB of 161 Kt and a likely maximum of 195 Kt.

Table 9-7: Annual egg production and SSB estimates for North Sea plaice in 2004. Egg development to temperature relationship from Fox *et al.* (2003). Atresia assumed to be 0.

Area	A	B	C	D	Total
AEP estimate Z=0 (*10^{12})	1.82	6.08	3.27	5.11	
AEP estimate Z=T (*10^{12})	2.58	7.50	3.76	5.78	
CV on total AEP estimate #					26%
Fecundity (eggs g^{-1} female)	255*	255	235	185	
Sex ratio	1:1	1:1	1:1	1:1	
SSB estimate Z=0 (tonnes)	14 252	47 663	27 834	55 229	144 979
SSB estimate Z=T (tonnes)	20 205	58 790	32 011	62 536	173 543

*** taken from area B. # CV from combined spatial variability in stage 1A production between the survey areas.**

9.2.3.5 Comparison with previous studies

The date from Heessen and Rijnsdorp (1989) were available to the current study. As the current study (2004) had greater spatial coverage than that of Heessen and Rijnsdorp (1989), the estimates from 2004 were reworked into the survey areas of Heessen and Rijnsdorp to allow direct comparisons (see Figure 9-4). The Fox *et al*. (2003) temperature to egg development relationships were applied to the Heessen and Rijnsdorp egg abundances to obtain comparable daily production estimates.

It is remarkably clear that in some of the sampling areas the production of plaice eggs appears not to have changed greatly between 1987, 1988 and 2004 (Figure 9-9). Areas 0 and I show no marked changes in magnitude or timing of spawning, these can be considered the eastern Channel and Southern Bight. In the Dogger Bank and German Bight areas (Heessen and Rijnsdorp areas II and III) the picture is less clear. The data appear noisier, and a lack of an earlier survey in area II in 2004 appears to prevent any robust comparisons on magnitude and timing of spawning in the Dogger Bank area, but the decline in production does appear similar. However the recent surveys do not support the evidence for wide scale spawning in the German Bight in the middle of February in 2004, as seen in both 1987 and 1988 (Figure 9-9).

The SSB associated to these AEP estimates show a marked changed over time (Table 9-8). Different estimates of fecundity were used for the 2004 and 1980s AEP. These are minimum estimates as the production at median age stage 1A was used. As suggested by the comparison of the seasonal production curves (Figure 9-9), the spawning in the Southern Bight appears very similar between the late 1980s and 2004. In the eastern Channel, the lower SSB in 2004 (45% lower) is probably explained by the failure to survey throughout the spawning season, and does not represent a true decline in the stock. However, in the Dogger Bank and the German Bight areas, the apparent decline is substantial, from a combined SSB of ≈ 60 Kt in the late 1980s to ≈ 20 Kt in 2004.

Sadly the raw data from Land (1991) are lost so other than comparing maps of production, no thorough comparisons with similar methods could be made. The data from Simpson (1959) is currently being re-entered from his published appendices and will be compared with the 1980s and 2004 findings.

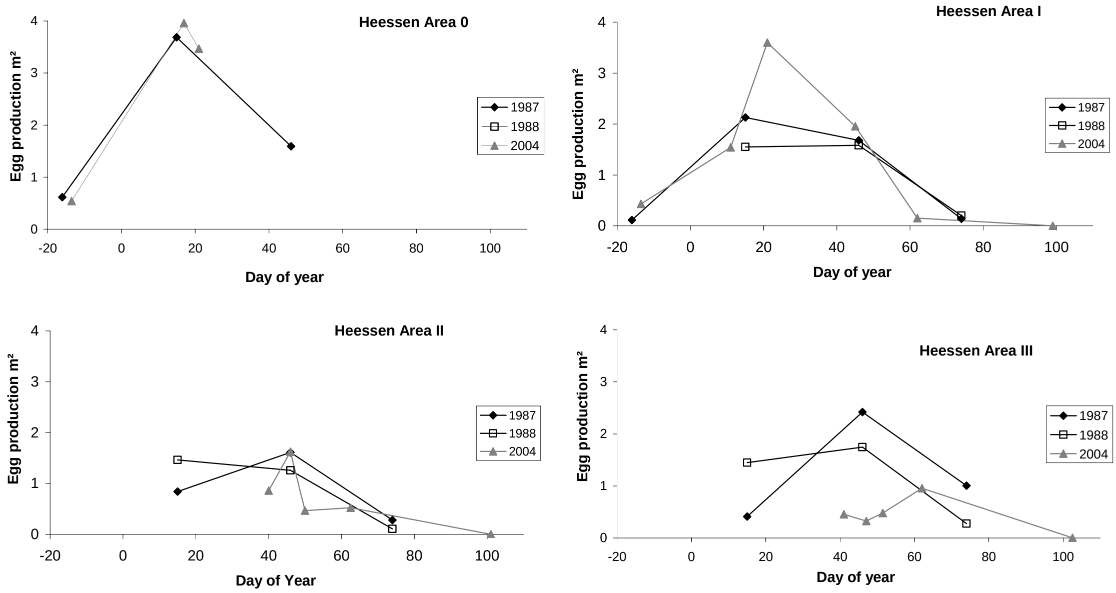

Figure 9-9: Seasonality in daily egg production in North Sea plaice in 1988, 1989 and 2004 in four areas. Estimates based on stage 1A egg production at catch (Z=0) from this study and Heessen and Rijnsdorp (1989). Areas shown in Figure 9-4, Fox *et al.* (2003) egg development rates used.

Table 9-8: Comparison of AEP estimates of SSB from this study and those of Heessen and Rijnsdorp (1989). Production is estimated with egg development to temperature relationship from Fox *et al.* (2003) and Z=0. Rijnsdorp (1991) estimates of fecundity applied to 1987 and 1988 AEP, and from the current study to the 2004 AEP.

Area from Heessen and Rijnsdorp*	0	I	II	III	Total
AEP estimate 1987 (*10^{12})	1.60	2.68	3.11	3.18	
AEP estimate 1988 (*10^{12})		1.93	3.13	2.83	
AEP estimate 2004 (*10^{12})	0.88	3.10	1.24	0.99	
Sex ratio	1:1	1:1	1:1	1:1	1:1
SSB estimate 1987 (tonnes)	12 548	21 037	26 481	34 346	118 402
SSB estimate 1988 (tonnes)		15 128	26 612	30 598	108 704
SSB estimate 2004 (tonnes)	6 899	24 318	10 552	10 708	53 471

*** see Figure 9-4. Fecundity in area I applied to area 0.**

9.2.3.6 Comparison of AEP estimates of SSB and the standard ICES stock assessment for North Sea plaice

The AEP derived estimate of SSB for plaice in the southern North Sea in 2004 was similar to that from the XSA stock assessment (Figure 9-10). For this analysis the spatial areas from the 2004 surveys were applied to the 1988 and 1989 surveys. The 1988 and 1989 estimates of SSB were slightly lower than those estimated by XSA. Further investigation of this difference is required, including consideration of varying sex ratios. This is the first time that an XSA derived estimate of SSB for plaice broadly agrees with that of an AEP (see Armstrong *et al.*, 2001; Kennedy 2006).

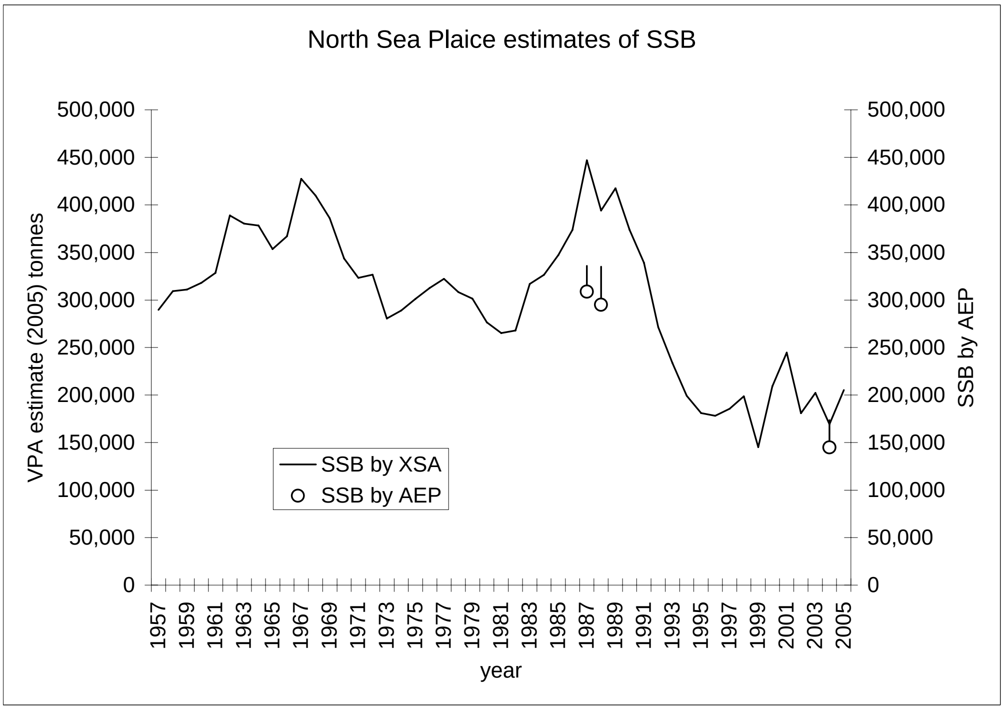

Figure 9-10: Comparison of AEP SSB with the ICES stock assessment using XSA (ICES, 2006). Circles denote the AEP estimate of SSB using egg production at the median age of egg stage 1A, whilst the top of the linked vertical bars denote the AEP estimate of SSB using the egg production at spawning (derived by mortalities varying due to temperature, Dickey-Collas *et al*, 2003). Egg development rates were based on Fox *et al.* (2003).

9.2.4 Conclusions

9.2.4.1 Methods

For much of the discussion about AEP methods see Armstrong *et al*. (2001) and Hunter and Lo (1993). It is clear that there are still many assumptions in current methods of AEP which are still yet to be properly assessed. The current work did not investigate the empirical evidence for Z, the likely variation in sex ratio, the variance introduced by the egg development rates, annually differing rates of atresia, the variance in the fecundity estimation and errors introduced by poor staging of eggs. The “pseudo-synoptic” nature of the surveys was not accounted for, and no geostatistical or GAM methods were used (see Fox *et al*., 2000). However as the methods broadly followed those of previous similar studies (Daan, 1981; Heessen and Rijnsdorp, 1989; Horwood, 1993a; b; Armstrong *et al*., 2001), the preliminary estimates are felt to be robust to scrutiny. The sensitivity analysis of using the Fox *et al*. (2003) egg development rates compared to Ryland and Nichols (1975) show that, as expected, when temperatures where higher there was a greater influence in the choice of model, this was apparent in sample area A (the eastern Channel). However as Fox *et al*. (2003) argues, their work was based on more experiments and on many more crosses of parents.

The 2004 ichthyoplankton survey of the North Sea provided a very good coverage of the southern Bight, and allowed acceptable comparisons with previous studies. As mentioned above, the temporal coverage was poor in areas A and D. This however did not prevent comparisons with previous studies.

The sampling for fecundity could have been more extensive, and it is not known how representative the German Bight sample was of the whole population in that area, as a replicate sample could not be collected. However, if the fecundity was higher in the German Bight, then the estimates of SSB would be ever lower than the current approach suggests.

9.2.4.2 Comparison with previous studies

The patterns of egg production in the eastern Channel and Southern Bight appear similar in the late 1980s and 2004. This may also be the case in the Dogger Bank area, however there are clear suggestions that the production of plaice eggs in the German Bight has changed since the late 1980s. Other data sources of plankton surveys are being sought to add to the time series and to allow further comparisons to be made.

9.2.4.3 Comparison with XSA, and impact in terms of the new assessment model

The current AEP estimate of North Sea plaice SSB is in broad agreement with the current ICES standard XSA stock assessment. The AEP method in other seas has suggested that SSBs from empirical ichthyoplankton data are higher than the standard XSA results. In the Irish Sea this has consistently been by a factor of three. This has not been the case here. The decline in SSB from 1988 to 2004 was approximately by 60% as estimated by XSA, and was by 50% as estimated by AEP. The AEP method supports the current ICES XSA stock assessment both in terms of the relative trend in SSB and the current absolute biomass. The AEP also suggests that most of this decline occurred in the Dogger Bank area and the German Bight.

10 Correlate the distribution patterns of eggs and larvae to hydrographic features and investigate potential physical/biological linkages

A CTD profile was carried out at each station in the sampling area north of 55N. Measurements of surface and bottom salinity/temperature were entered in the biological database, and a separate database was established for all CTD profiles from the programme. In order to cover the hydrography from the area south of 55N, supplementary CTD information from the International Bottom Trawl Surveys was added to the database. The coverage of stations for hydrographic information from the period 18/2–22/3 is shown in Figure 10-1.

Hydrographic characteristics are analysed using surface and bottom salinity, temperature and water density, and using vertical sections of the same measures. Examples of surface salinity and surface density contouring for the full coverage period (18/2–22/3) are shown in Figures 10-2 and 10-3, respectively. The hydrography is greatly influenced by river outflow and the currents of relatively fresh water flowing along the coasts. The coastal currents along the Dutch, German and Danish coast (Jutland current), and the Baltic outflow along the Norwegian coast (Norwegian coastal current) dominate, while the freshwater influence along the British coast is less marked. A water mass of intermediate salinity/density is seen between the coastal currents and the central water of Atlantic origin, this mixing zone is referred to as the Region Of Freshwater Influence (ROFI).

Hydrographic fronts are formed between the coastal currents, the ROFI and the central saline water mass, visible as marked changes in surface water density (Figure 10-3). The degree of change in surface density is calculated and a preliminary analysis is shown in Figure 10-4. This illustration of surface fronts indicates frontal zones off all coasts, and in an extended area south of Dogger Bank. Frontal zones are also apparent in hydrographic vertical sections across the North Sea, as for example along 55º15’N (Figure 10-5).

While the eggs and larvae of different species are often distributed in different sections of the North Sea, the major concentrations of these repeatedly are found in, or in the vicinity of, hydrographic frontal areas. This is for example apparent for cod eggs (Figure 10-6), haddock eggs (Figure 10-7) and for sandeel larvae (Figure 10-8). In cross frontal sections most species show high abundance of eggs/larvae in the frontal zone, but often the respective peaks in species abundance are displaced from each other. Hence observations indicate an influence from frontal hydrography that is to some extent species specific. The analysis of linkages between distributional patterns of eggs/ larvae and the specific hydrographic features is still ongoing.

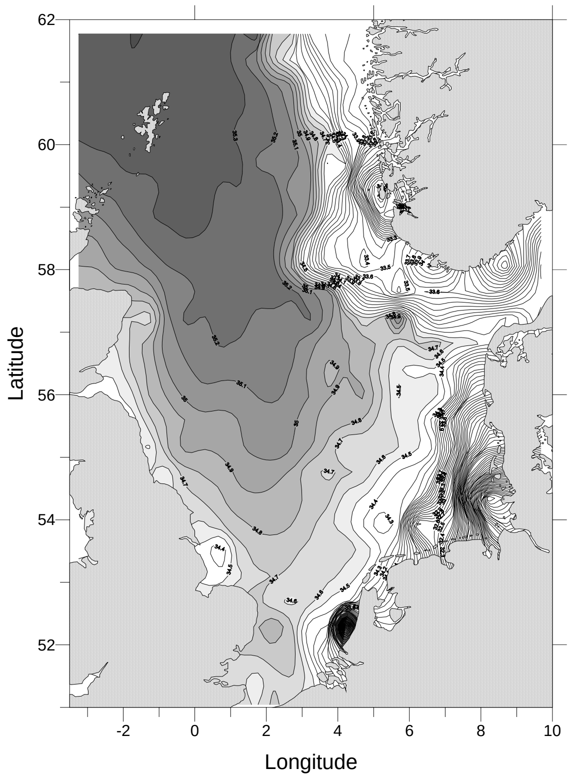

Figure 10-1: Location of the hydrographic stations (contours indicate bathymetry).

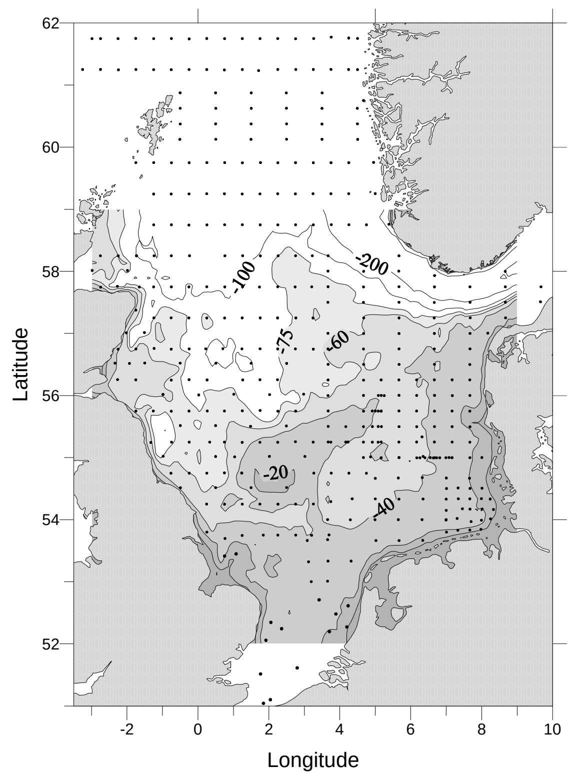

Figure 10-2: Surface salinity (psu).